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VLBI Data Acquisition Terminal Modernization at the Deep Space Network

C. García-Miró [2], S.P. Rogstad [1], R. Navarro [1], J.E. Clark [1], C.J. Naudet [1], C.S. Jacobs [1], C.E. Goodhart [1], L.A. White [1], J.T. Trinh [1], M. Soriano [1], D. Wang [1], E.H. Sigman [1], G. Martinez [3], J.V. Luvalle [3], I. Sotuela [2], P.A. Pope [4], S. Horiuchi [4], J. Lobo [2], R. Alonso [2], L.G. Snedeker [5]

[1] *Jet Propulsion Laboratory/NASA, California Institute of Technology, Pasadena, CA*
[2] *Madrid Deep Space Communications Complex/NASA, INTA, Madrid, Spain*
[3] *ITT Exelis, Monrovia, CA*
[4] *Canberra Deep Space Communications Complex/NASA, C.S.I.R.O., Canberra, Australia*
[5] *Goldstone Deep Space Communications Complex/NASA, ITT Exelis, Monrovia, CA*

Contact author: C. García-Miró, e-mail: `cgmiro@mdscc.nasa.gov`

Abstract

The Deep Space Network (DSN) is replacing the aging Mark IV Data Acquisition Terminal (DAT) with a digital backend, the DSN VLBI Processor (DVP). It is based on the Wideband VLBI Science Receiver (WVSR), a custom-made open-loop digital receiver developed at JPL that is successfully supporting differential-VLBI for spacecraft navigation (DDOR) and other radio astronomy applications, e.g. Earth orientation, astrometry, and spectroscopy observations.

From the WVSR the new acquisition terminal has inherited the Intermediate Frequency (IF) digitizer module, the firmware architecture, and monitor and control software. Among the new features, the DVP improves considerably the recording rate providing at least 2 Gbps with the goal of achieving 4 Gbps; uses a CASPER ROACH board for real-time Digital Signal Processing and channelization and streams the data into a Mark 5C recorder. This paper describes in detail the DVP in the context of similar digital developments (e.g., RDBE, DBBC).

As the new backend will not use the standard Field System environment to perform the VLBI observations, efforts are under way to make it compatible with non-JPL correlators, providing monitor and calibration data in the appropriate format. Lately an important effort has been made in the DSN towards automation of VLBI data acquisition using the Automation Language for Managing DSN Operations (ALMO). The automation process will be adapted for the new DAT.

1. Introduction

Since the origin of the Very Long Baseline Interferometry (VLBI) technique, the contribution of NASA's Deep Space Network (DSN) has been crucial, providing outstanding sensitivity and resolution. For instance, the first trans-Pacific VLBI observation was performed using antennas of the DSN (Gubbay *et al.*, 1969). Since that milestone, the DSN has contributed to different radio astronomy research areas through participation in a large number of VLBI observations: galactic and extragalactic studies, with special emphasis on observations of supernova remnants and gravitational lenses, participation in space VLBI observations as well as remarkable results in astrometry, celestial reference frames, and geodesy.

Nowadays the DSN supports many different types of VLBI observations from various customers within the Jet Propulsion Laboratory (JPL) and externally. The JPL Reference Frame Calibration

(RFC) group is responsible for providing the Earth Orientation Parameters, determined during the VLBI Time and Earth Motion Precision Observations (TEMPO), and it also realizes and maintains an extragalactic reference frame for JPL navigation purposes (García-Miró *et al.*, these proceedings). The JPL Delta Differential One-way Ranging (DDOR) group uses VLBI techniques to reference the positions of spacecraft with respect to distant quasars. Moreover, proof-of-concept VLBI applications for navigation, such as phase referencing and same beam interferometry, are also performed.

Among our external customers are the European VLBI Network, the International VLBI Service for Geodesy and Astrometry, and the Australian Long Baseline Array. Other non-VLBI customers use the same hardware to perform their observations such as the Host Country Programs in Spain and Australia or the Guest Observer Programs.

The purpose of the VLBI Data Acquisition Terminal modernization task presented here is to replace the aging Mark IV DAT hardware with a modern Digital Backend system, the DSN VLBI Processor (DVP). It is based on the Wideband VLBI Science Receiver (WVSR), a custom-made open-loop digital receiver developed at JPL (Jongeling *et al.*, 2006) that is already successfully supporting DDOR and other radio astronomy applications. The DVP has inherited from the WVSR the IF digitizer module, the firmware architecture, and the monitor and control software, but it contains new key elements such as the CASPER ROACH board (Casper, 2012) and the Mark 5C recorder (Haystack, 2008). It is compatible with other digital developments (e.g., DBBC, RDBE).

2. DSN VLBI Processor Overview

This section describes the different elements that constitute the DVP (Navarro *et al.*, 2011): IF switch, IF digitizer module, ROACH transition module and ROACH board, Mark 5C recorder, and the control computer. The following subsections describe in detail each component. Figure 1 represents a block diagram of the system.

2.1. Signal Selection and IF Digitizer Module

Unlike most VLBI sites, each DSN complex has many antennas available for VLBI observations, each with different receiving bands. Therefore the DVP should be able to accept a wide range of input signals. In this respect the DVP is compatible with all available DSN receiving bands: L-band (1.4–1.9 GHz), S-band (2.2–2.3 GHz), X-band (8.2–8.6 GHz), K-band (18–26 GHz), K-band phase-II (25.5–27.0 GHz), Ka-band (31.8–32.3 GHz), and Q-band (38–50 GHz). An IF switch selects from among 12 inputs at the DSN intermediate band (IF) of 100–600 MHz, in order to support at least three antennas per complex. The switch selects two IF outputs, each one covering up to 500 MHz of bandwidth.

The two selected IF signals are digitized using the JPL IF sampler module. The sampler module provides A/D 8-bit samples at 1280 MHz, generated from a 100 MHz reference provided by the frequency and timing distribution subsystem. It has a digitally controlled built-in attenuator. The digitizer is already in operational use in the DSN and was specially designed to avoid spurious signals for spacecraft tracking. In fact, spurious signals are attenuated 75 dB below the A/D saturation level thanks to the optical isolation from the digital processing backend, using an interface transition module to connect to the ROACH board. This feature makes it very suitable for astronomical spectral line studies.

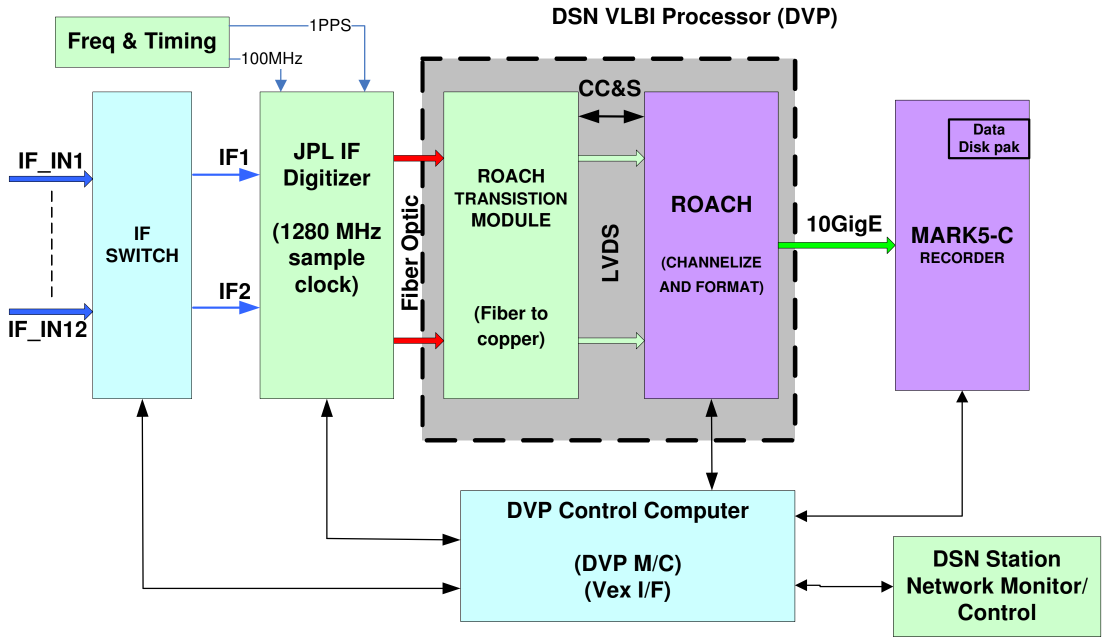

Figure 1. DVP block diagram showing main components: JPL hardware (JPL IF digitizer and ROACH transition module), non-JPL hardware (ROACH board and Mark 5C recorder), and COTS hardware (IF switch and DVP control computer).

2.2. Channelization and Sub-band Filtering

Digital Signal Processing and Channelization is performed using a ROACH board (Casper, 2012). The channelization is broken up into two stages (Figure 2). The first stage is a polyphase filter bank that breaks up the input signal (500 MHz bandwidth) into seven fixed bands of data, each 160 MHz wide (complex). Channels are centered at 80, 160, 240, 320, 400, 480, and 560 MHz, respectively. The second stage selects one of the seven first stage wideband inputs, applies a digital mixer for precise channel location selection, and using a cascade of downconverting filters (CIC & FIR type) provides a total of 32 upper/lower or 16 complex sub-channels (in-phase and quadrature-phase). The output bandwidth per channel is variable from 16 MHz to 0.5 kHz (or from 32 MHz to 1 kHz for the complex sub-channels), and the supported bits per sub-channel are 8, 4, 2, or 1 bits. The FIR filter's coefficients are selected in order to get a maximum of 0.1 dB ripple in the passband and at least 40 dB attenuation in the stopband. Additionally, the system has the ability to detect in real-time phase calibration signals for different sub-channels.

2.3. Recording and Control

The DVP streams the data from the ROACH board through a 10GigE connection to a Mark 5C recorder (Haystack, 2008) providing at least 2 Gbps data rates with the goal of achieving 4 Gbps. Data is stored on Mark 5 SATA disk packs in VDIF format. The modernization task also includes incremental improvements to the JPL VLBI Software Correlator to support Mark 5C hardware and new data formats.

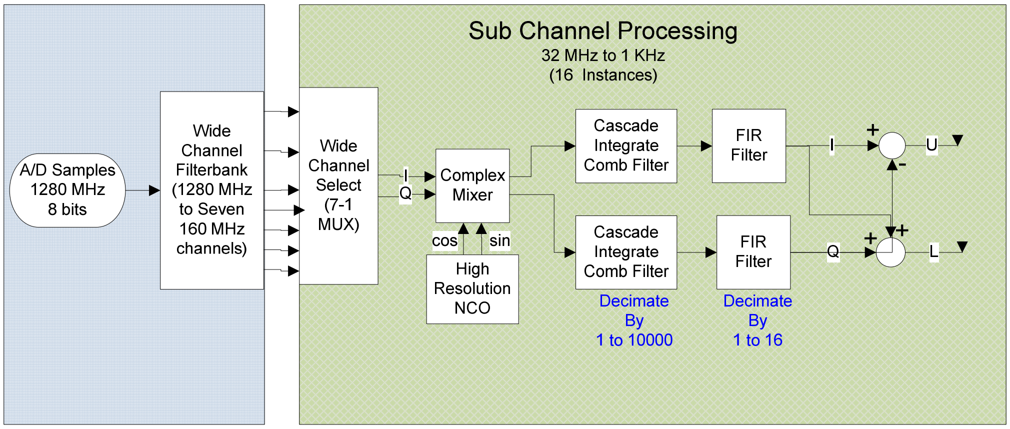

Figure 2. DVP channelization (left box) and sub-band filtering (right box).

The PC-Field System computer is replaced by a Dell PowerEdge R210 server as Data Processor and Controller (DPC) computer and uses the driver, command, modeling, and monitoring & control WVSR-based software instead of the standard Field System application. The DPC computer interfaces to the DSN Monitor & Control infrastructure (NMC), which interacts with all DSN subsystems (RF microwaves and noise diode control, antenna control, etc.) via directives, responses, and monitor data.

3. DVP Functionality Requirements from Customers

The modernization task has to maintain compatibility with other VLBI centers for DSN support of international VLBI and Host Country activities. As the Field System application will not be used to support the VLBI observations, a translator will produce a Field System type log compatible with the correlators and will contain the following information:

- System temperature monitoring in ANTAB format: the total power on each channel will be calculated at the digital stage with appropriate dynamic range.
- Antenna calibration parameters in rxg format: the DSN performs antenna calibration tasks using custom built tools (Rochblatt *et al.*, 2007) that substitute Field System calibration applications (fivept and onoff procedures, gnplt application, etc.).
- Phase calibration signal in /pcald/ notation.
- Antenna status in /onsource/ and /flagr/ notation.
- Weather in /wx/ notation.
- Mark 5C monitor data.
- Equivalent gps-fmout values: currently the DVP digitizer does not provide a 1pps signal from its internal clock; a solution must be found to provide a gps versus digitizer time offset.

DVP users should provide VEX 2.0 files that contain appropriate $*blocks* for DVP configuration and precessed coordinates for the observing date.

4. Automation of VLBI Operations

Lately an important effort has been made in the DSN towards automation of the VLBI operations. Pre-pass, in-pass, and post-pass tasks are performed automatically, reducing manual input and subsequently minimizing critical operator errors. As a side effect, countdown (set up) and teardown times have been reduced considerably. This feature makes use of the DSN Monitor & Control infrastructure (NMC) automation scheme, using Connection Blocks (scripts) written in Automation Language for Managing Operations (ALMO), a superset of Tcl/Tk (Bokor, 2000). The automation scheme provides the ability for simultaneous subsystems configuration and closed loop directive/response control. The automation process will be adapted for the DVP operations.

5. Conclusions

The digital backend presented here will enhance considerably the quality of the DSN VLBI observations. Among many other advantages, the digitizer module decreases the spurious signals, and the digital linear filters have reduced instrumental artefacts and no channel-to-channel variations. The usage of the Mark 5C recorder will allow us to increase the recording rate up to at least 2 Gbps to sample the whole 500 MHz instantaneous bandwidth available (per polarization). This will provide the DSN with an unprecedented sensitivity: e.g., in a single baseline formed by two 70-m antennas, we will achieve a 1.4 mJy sensitivity at K-band, with just one-minute integration (1-σ). As a result the DVP will make the DSN a world-class radio astronomy instrument.

Acknowledgements

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References

[1] Bokor, E., ‘Automating Operations for NASA’s Deep Space Network (DSN)’, IEEE A. Conf., 2000.

[2] Reconfigurable Open Architecture Computing Hardware (ROACH), CASPER, 2012.

[3] Gubbay, J. S., *et al.*, ‘Trans-Pacific Interferometer Measurements at 2.3 GHz’, Nature, 222, 730, 1969.

[4] García-Miró, C., *et al.*, ‘The X/Ka-band Extragalactic Reference Frame’, Proc. of IVS GM, 2012.

[5] Jongeling, A. P., *et al.*, ‘Digital Front End for Wide-Band VLBI S. Receiver’, NASA Tech. R., 2006.

[6] MIT Haystack Observatory, ‘Mark 5C Specification’, Mark 5 memo #57, 2008.

[7] Navarro, R., *et al.*, ‘Impl. Issues and Choices for VLBI DAT in DSN’, 9th US VLBI Tech. M., 2011.

[8] Rochblatt, D., *et al.*, ‘New Antenna Calibration Techniques in the DSN’, IPN Prog. Rpt. 42-169, 2007.